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PRELIMINARY ASSESSMENT OF NEWLY AVAILABLE DIGITAL SEISMIC DATA FROM KAZAKHSTAN

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This technical report has been reviewed and is approved for publication.

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13. ABSTRACT *(Maximum 200 words)*

We describe the salient characteristics of examples of digital seismic data recorded at the Borovoye Geophysical Observatory, Kazakhstan. Our data resulted from a request made in 1990, and we have three-component recordings on several different types of instrument for 30 nuclear explosions and 10 earthquakes going back to 1969. Much of the data is an excellent quality, though at present we do not know the precision with which instrument responses are measured.

Borovoye is about 700 km from the Semipalatinsk nuclear test site. We have measured RMS *Lg* for Semipalatinsk explosions in the new data, and find by comparison with similar measurement at NORSAR (Norway) and WMQ (China) that the scatter in Borovoye RMS *Lg* is only about 0.05 magnitude units.

14. SUBJECT TERMS
Lg-waves, seismic instrumentation, nuclear explosions, Kazakhstan

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PRELIMINARY ASSESSMENT OF NEWLY AVAILABLE DIGITAL SEISMIC DATA FROM KAZAKHSTAN

Paul G. Richards and Won-Young Kim

INTRODUCTION

This report concerns a unique seismological observatory that has operated since the 1960's. Located in Kazakhstan, for over 25 years it has been recording and archiving up to 50 channels of digital data each day.

This project began for us in the spring of 1990 at the annual workshop of the Incorporated Research Institutions for Seismology (the IRIS Consortium). Seismologists from the Soviet Union attended and told us that they had permission to describe a geophysical observatory at Borovoye, near Kokchetav in Northern Kazakhstan, which had operated digital seismometers since 1966. They said there was a large tape archive and that much of the data were of excellent quality and would probably be made available on request - even the data for nuclear explosions.

In about December, 1990, one of us made a data request for signals from about 30 nuclear explosions, and from several earthquakes near nuclear test sites.

At the next IRIS workshop, held in March, 1991, we received a nine-track tape that had 43 examples of three-component digital data, all recorded at Borovoye, Northern Kazakhstan.

In this report, we describe some of the data we were given, what we have learned about the instrument responses, and some of our preliminary analyses.

STATION CHARACTERISTICS

The Borovoye seismic station (BRV), with coordinates 53° 03' 29" N; 70° 16' 58" E (see Figure 1), is located on a pluton about 200 km across with an ill-defined but deep Moho and monolithic granites. The station owes its existence to its ability to pick up signals very well from the Nevada Test Site. The data at Borovoye of seismic signals from Nevada explosions have *P* waves two or three times larger that would be expected on the basis of globally averaged magnitudes for Nevada explosions. The status of "observatory", with continuous analog recording, was accorded to Borovoye in 1965. The early deployment of seismic instruments was in a tunnel driven horizontally into granites rising to the south of a lake about 4 km across, but now all seismometers are in a 15-meter deep vault with three chambers.

There are three digital systems. The first BRV digital seismic system, known as KOD began recording in 1966 and operated continuously from 1967 to 1973. It is based on three component, short-period seismometers, and is important as one of the few digital systems in the late 1960's - early 1970's. From the perspective of the standard convention on ground motion polarity, in which motions in the up, north and east directions are taken as positive, we note that all KOD signals have the opposite convention. The second BRV digital system, known as STR, has operated from March, 1973 to the present day. It consists of two separate parts: STR-SS, which is intended mainly for low-gain recording, and STR-TSG, which includes six long-period and seven short-period Kirnos seismometers, most recorded at two gain levels for a total of 20 data channels. The highest sensitivity is 100,000 counts/micron, based on a short-period Kirnos with a special magnet, and a low-noise amplifier. The third BRV digital system, known as ASST and installed in April, 1990, uses broad-band forced-balance seismometers and is still under test.

Figures 2 and 3 show instrument responses for several instruments of the KOD, STR-TSG, and STR-SS systems. Table 1 shows parameters of instruments in each of the four systems. Figure 4 shows calibration pulses for the TSG system, together with the synthetic response we have obtained at Lamont in terms of poles and zeros.

EXAMPLES OF EXPLOSION DATA

In Figure 5 is shown a detailed location map for several nuclear explosions at the Shagan River test site, East Kazakhstan. In Figure 6 is shown a set of seven seismograms for these

events, all recorded at Borovoye on the same instrument, showing excellent data for *Pn* and the other main regional phases *Sn*, *Lg* and *Rg*. Notice that even though these events are separated by no more than twenty kms, there is considerable variability in amplitude of the regional phases recorded at BRV, over a distance of about 700 km. Figure 7 shows the same data, with an expanded time scale. We comment below on the *Lg* signals, which we have compared with NORSAR and WMQ for these same events. Note also the appearance of the first trace in Figures 6 and 7, which turns out to be a recording of a double explosion.

For the Joint Verification Explosion conducted at the Shagan River test site on 1988 September 14, we have several channels including the TSG short period and long period channels (see Figure 8) and a three-component broad-band record (see Figure 9).

As representative examples of the Borovoye data for explosions at Novaya Zemlya, Figure 10 shows a three-component short-period record for the event of 1988 December 4. It may be seen that the short-period *Lg* is quite weak at this distance, almost 2400 km. Figure 11 shows a three-component long-period record for the Novaya Zemlya explosion of 1988 May 7.

EXAMPLES OF EARTHQUAKE DATA

When we had the opportunity in 1990 to make a data request, a puzzle from 1969 came to mind. Figures 12 and 13 were published 20 years ago, and show (respectively) an m_b/M_S diagram with an event marked as KA appearing in the part of the diagram normally associated with explosions, and the data for this event reported at the Worldwide Standard Station at Kabul. For its body wave magnitude, this event of 1969 May 1 has a very low surface wave magnitude. But there is a problem with measuring the surface wave magnitude because there was a concurrent large earthquake in Tonga that generated large surface waves all around the world. Even at Kabul, so much nearer the Kazakhstan event, the surface waves from Kazakhstan are small and their magnitude is impossible to measure accurately. Figure 14 shows the three-component Borovoye digital data, recorded on the KOD system at a distance of about 10° from the 1969 event. Figure 15 shows the same data with an expanded time scale. Figure 14 is slightly clipped for the *Lg* phase, but otherwise it is excellent data. For example it is good enough to analyze particle motion in detail, and just after the *P* arrival we find a quite strong signal arriving off azimuth by several degrees.

Another interesting Kazakhstan earthquake occurred on 1976 March 20, and in Figure 16 we show the Borovoye short-period digital data. In Figure 17 is a comparison of this earthquake with the signal from the Joint Verification Explosion of 1988 at Shagan River. We have incorporated a polarity reversal of the earthquake to make the comparison, and it is clear that the first arrival of the earthquake is a dilatation. This earthquake was a thrust, and all teleseismic arrivals showed a compression. Figure 18 shows the same data with an expanded time scale.

EXAMPLES OF DOUBLE EXPLOSIONS

It has long been known that double explosions are sometimes carried out at the Kazakhstan test sites (Sykes and Ruggi, 1989). Figure 19 shows an example from December, 1972, recorded teleseismically at NORSAR. The larger *P* wave is slightly clipped, and for purposes of estimating an *Lg* magnitude of the larger event, it is necessary to make a correction for the contribution from the smaller event (see Ringdal, 1989).

From Borovoye, we requested two examples of double explosions. This data was included with the tape we received in March, 1991. In Figure 20 we display the Borovoye short-period data, which in each case is for an explosion at Degelen Mountain followed about 10 seconds later by a larger explosion at the Shagan River test site. The upper example of Figure 20 is the same double explosion from 1972 that was illustrated in Figure 19. The lower example in Figure 20 is the double explosion mentioned above, in Figures 6 and 7, occurring in 1978.

Since this is digital data, we can look just at the two Degelen signals on an expanded scale, and compare them. Such a comparison is shown in Figure 21. The instruments responses are

slightly different in 1972 and 1978, and a correction has been made to obtain data with the same response. It is clear from Figure 21, with its excellent agreement of the two wave forms recorded about six years apart, that these two events were located very close to each other.

ANALYSIS OF LG PRECISION

Next, we describe the measurements of the *Lg* signals recorded at Borovoye, and the stability of this measurement.

Figure 22 shows the work station display for our measurements of RMS *Lg*. We choose a window-length and plot the RMS value (more correctly, the logarithm of the root mean square averaged over the window) as this window is moved down the seismogram. As shown in the figure, the RMS value is indicated along with the corresponding group velocity. We have found in practice that our results on the stability of *Lg* do not change, whether we use a few tens of seconds or more than a minute for the *Lg* window. We had six events we could study that were recorded on the same instrument and that were not clipped.

Figure 23 plots our results for the five explosions which were big enough for a measurement to be made at NORSAR, almost 4000 km away. Figure 24 shows the comparison for all six of the events recorded at Borovoye, compared with RMS *Lg* recorded at the station WMQ of the Chinese Digital Seismograph Network. In both cases we find that the scatter of the data about a best fitting line is quite small, having a one sigma value of about 0.05 magnitude units on three degrees (Figure 23) or four degrees (Figure 24) of freedom.

CONCLUSIONS AND RECOMMENDATIONS

We now have 37 examples of digital data from the Borovoye Geophysical Observatory for nuclear explosions conducted at Shagan River, Novaya Zemlya, and Lop Nor. At least two of these examples are double explosions. We also have data on about 10 earthquakes (some regional, some teleseismic). We are pursuing the question of calibration, for all the many instruments for which we have so far received data. In the process of acquiring this data we have been given much information on what is clearly the most sophisticated seismic station ever operated in the Soviet Union.

If the research community in the United States deems these data valuable, then there will be some consideration of an effort to copy as much as possible of the whole archive at Borovoye into a modern format for use by seismologists in Russia and Kazakhstan, as well as the United States.

Such an effort may usefully be thought of as two separate steps. First to copy all the wide tapes (we believe there are about 7,000 of them, holding a total of about 70 gigabytes) to a modern recording medium. This would not be a a major project, but some consideration would have to be given to special staff support at BRV for the duration of the copying in addition to hardware. Second, to work with BRV personnel on the design of a suitable new format for the archive, to incorporate all of the available information on instrument responses (now recorded only on log books held at the observatory) and to implement the new format with appropriate quality controls. This second step would be a major project requiring a plan with milestones and an agreed schedule. It might take several years to execute.

We are not advocating either the first steps or the two steps together at the present time. But if the data we have so far acquired, supplemented by the data we have been told will be forthcoming, is found to be of high quality, then we expect to be making the case for salvaging and modernizing what clearly is a unique digital archive at Borovoye.

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Table 1. Instrument Response Characteristics at Borovoye Seismic Station.

System	Seismometer	Channel	T_s[a] (s)	D_s[b]	S_m[c] (unit/μm)	f_n[d] (Hz)	Rate[e] (sample/s)	Channel #
KOD								
	SKM-3	High-gain†	3.5	0.71	3000	2.0	33.3	1,3,4
		Low-gain (Z)*			300	2.0	33.3	-
	SKD	-	30.0	0.71	-	-	-	-
STsR-SS								
	SKM-3	High-gain	2.0	0.5	2000	1.8	41.7	1,7,8,9
		Low-gain			200	1.8	10.4	6,8,9
	SKD	High-gain	25.0	0.71	5.0	0.14	5.2	2,3,4
		Low-gain			0.5	0.14	5.2	-
STsR-TSG								
	KS	High-gain	1.5	0.71	4500	2.37	38.5	7,8,9
	KSM	High-gain	1.5	0.5	100000	1.43	38.5	10,11,12
		Low-gain			1000	1.43	38.5	3,4,5
	KSVM	High-gain (Z)	1.5	0.5	4600	1.43	38.5	2
		Low-gain (Z)			50	1.43	38.5	1
	DS	High-gain	20.0	0.71	50	0.1	3.2	19,20.21
	DSM	High-gain	28.0	0.71	1000	0.07	3.2	22,23,24
		Low-gain			10	0.07	3.2	15,16,17
ASSTs	SSM-S		2.0	-	250	-	-	-

(a) Ts = Seismometer natural period in second, (b) Ds = Seismometer damping constant critical damping = $1/\sqrt{2}$, (c) Sm = Nominal sensitivity in count/micron, (d) f_n = Normalization frequency where nominal sensitivity is measured, (e) Rate = Sampling rate in samples/second. † Acually this is base channel not necessarily a high-gain, * Only vertical component.

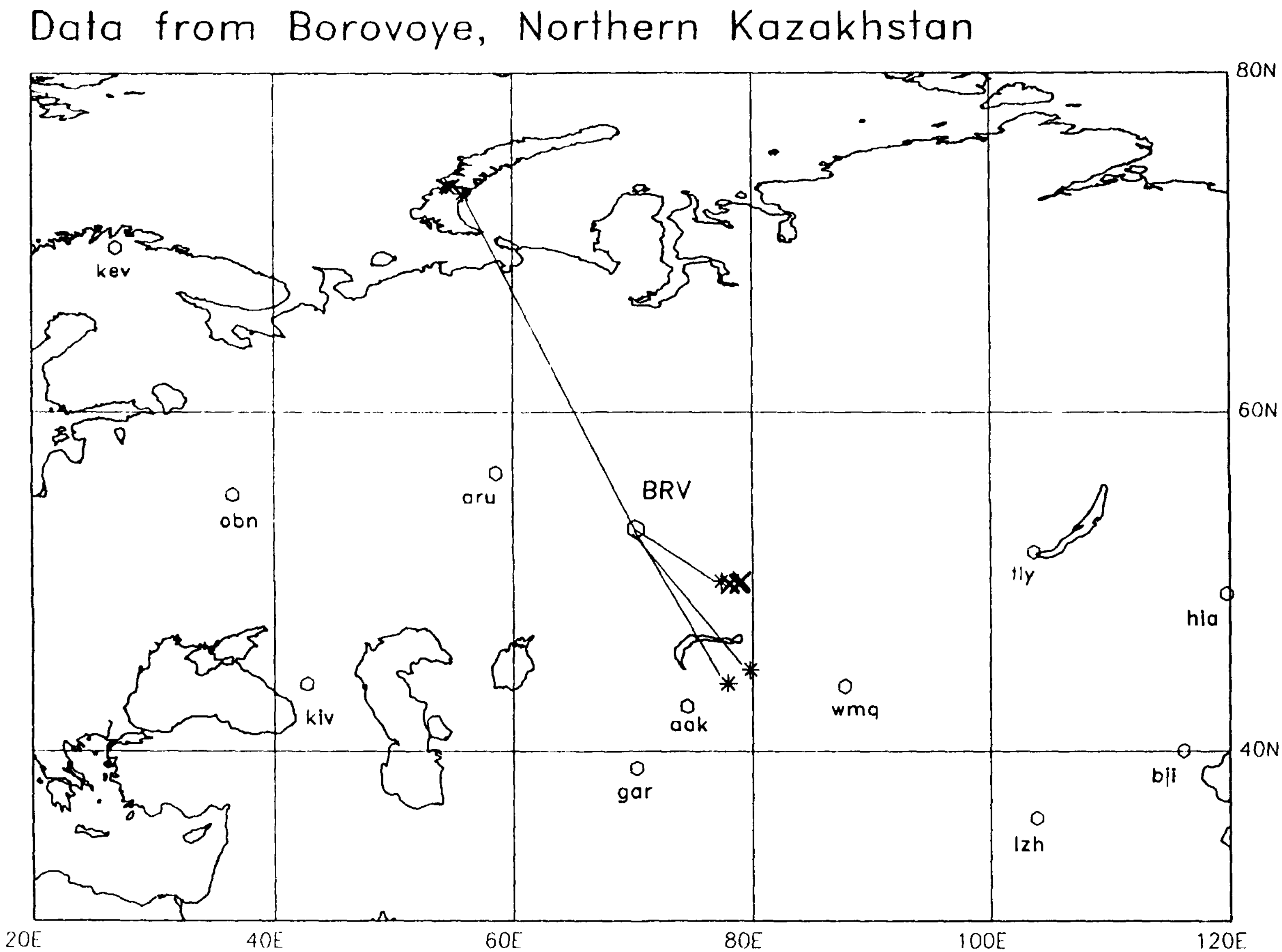


Figure 1: Location map. Borovoye is about 500 km north-west of the Semipalatinsk test site in Kazakhstan.

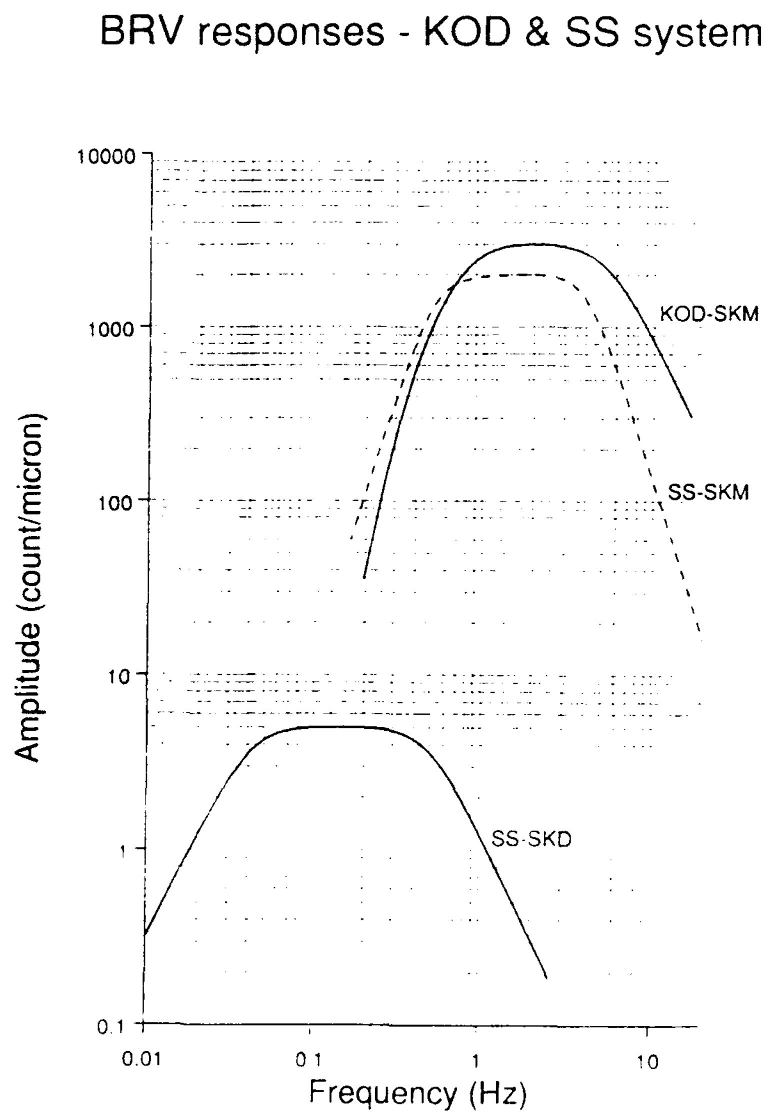


Figure 2: Response of instruments in the KOD and STR-SS systems.

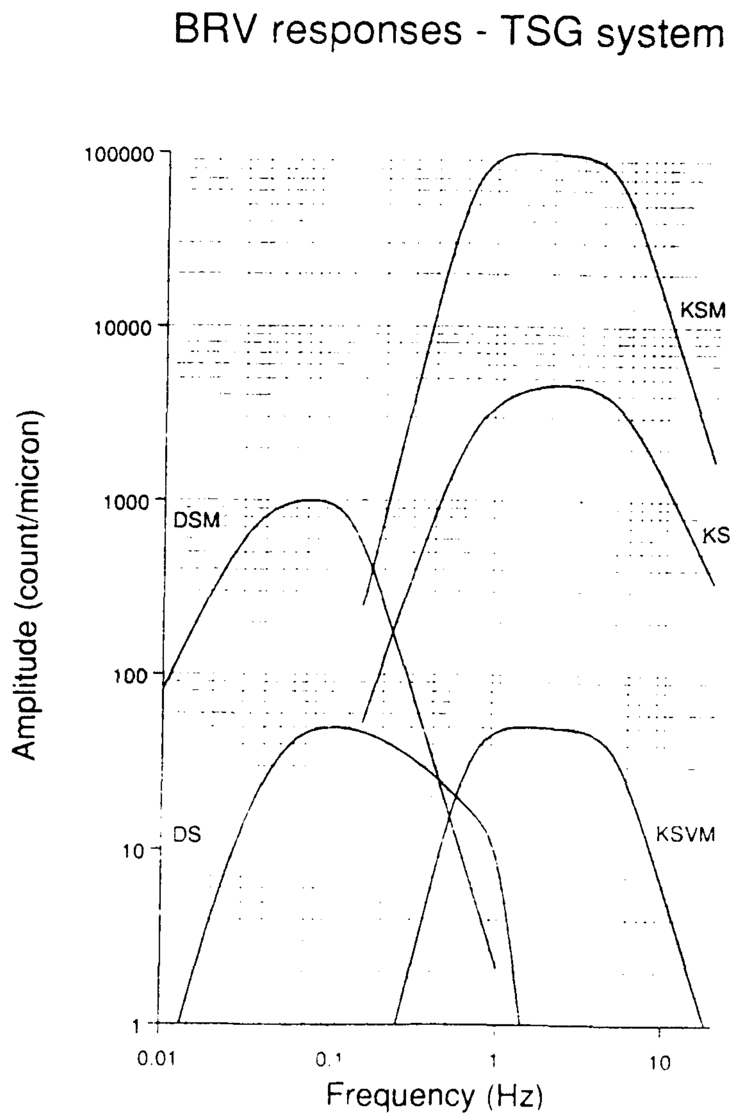


Figure 3: Response of instruments in the STR-TSG system

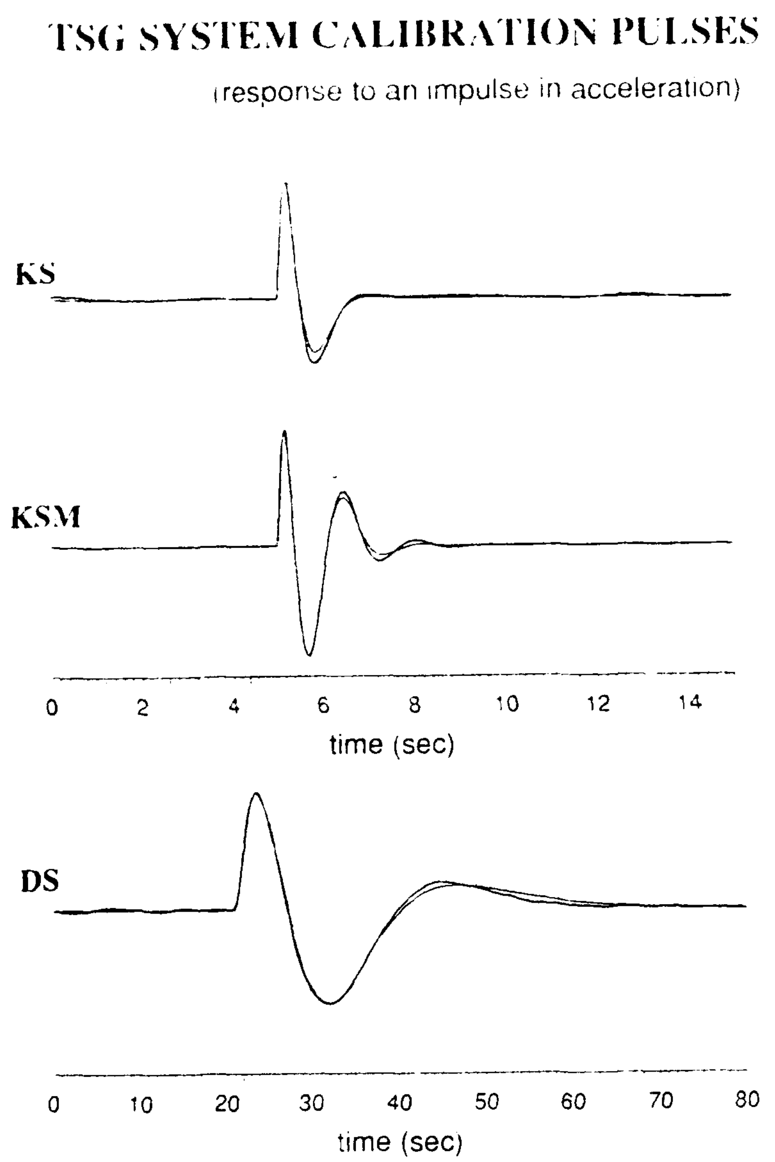


Figure 4: Comparison of actual and synthetic calibration pulses (based on poles and zeroes), for instruments in the STR-TSG system.

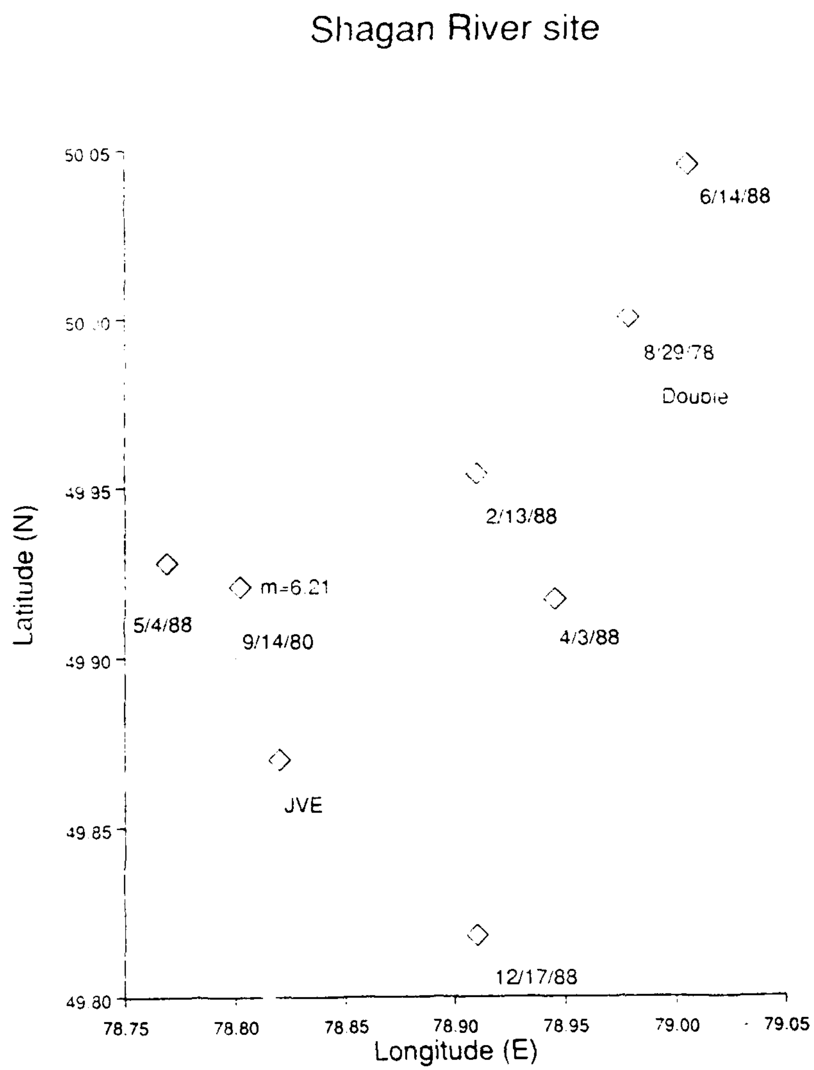


Figure 5: Detailed location map for selected nuclear explosions at the Shagan River test site.

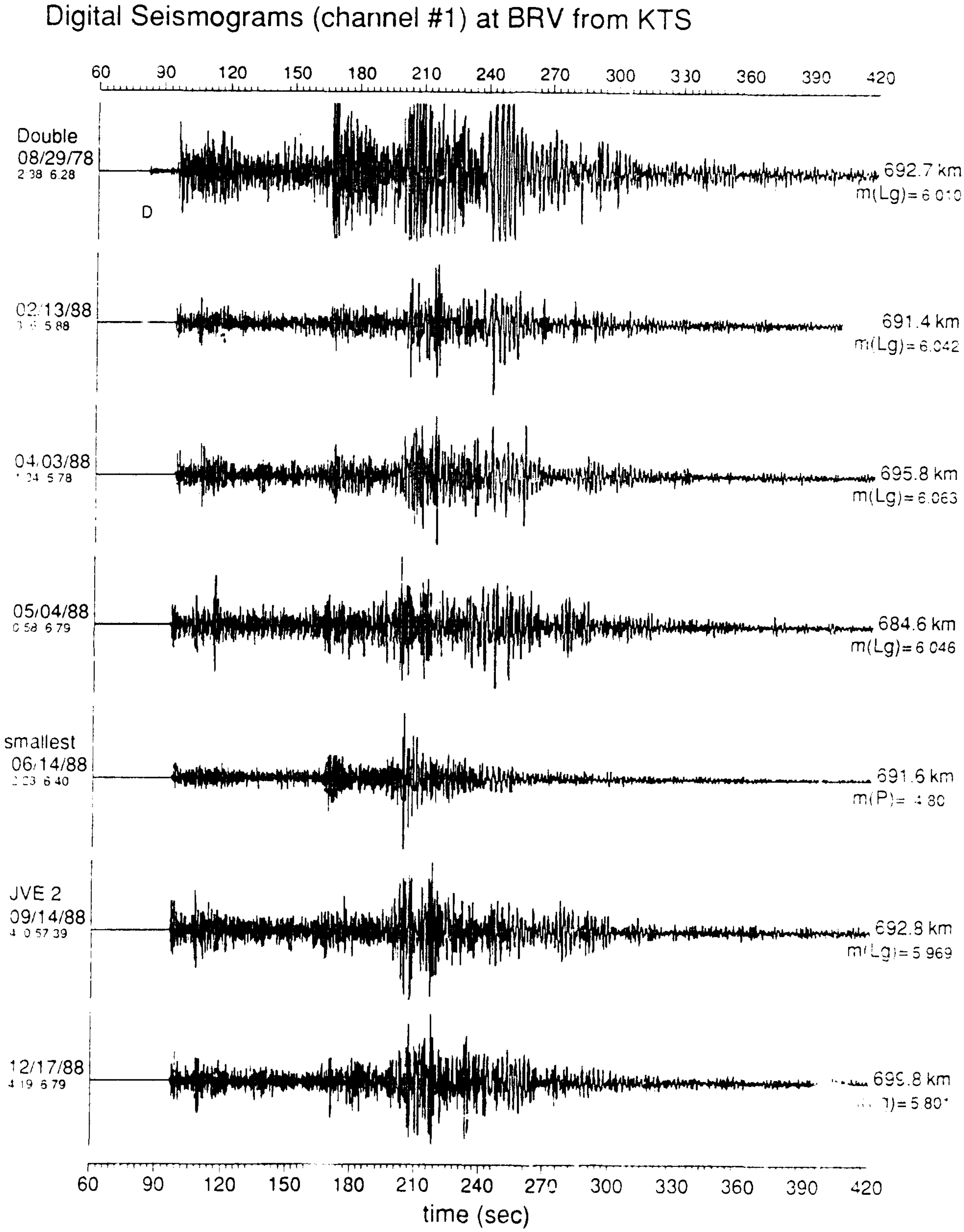


Figure 6: Seven examples at Borovoye of short-period vertical records for Shagan River explosions.

Digital Seismograms (TSG channel #1) at BRV from KTS

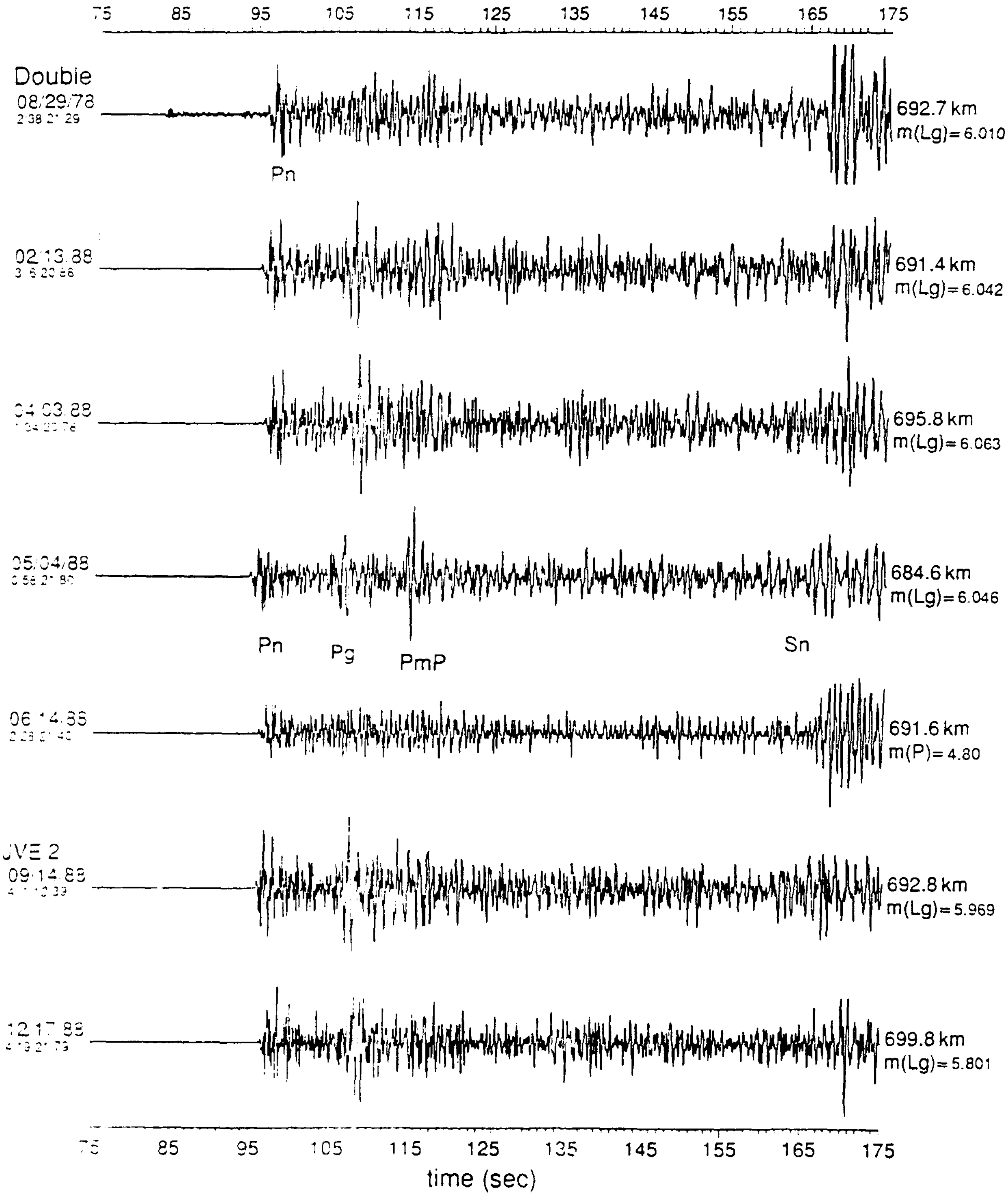


Figure 7: As Figure 6, but with expanded time scale.

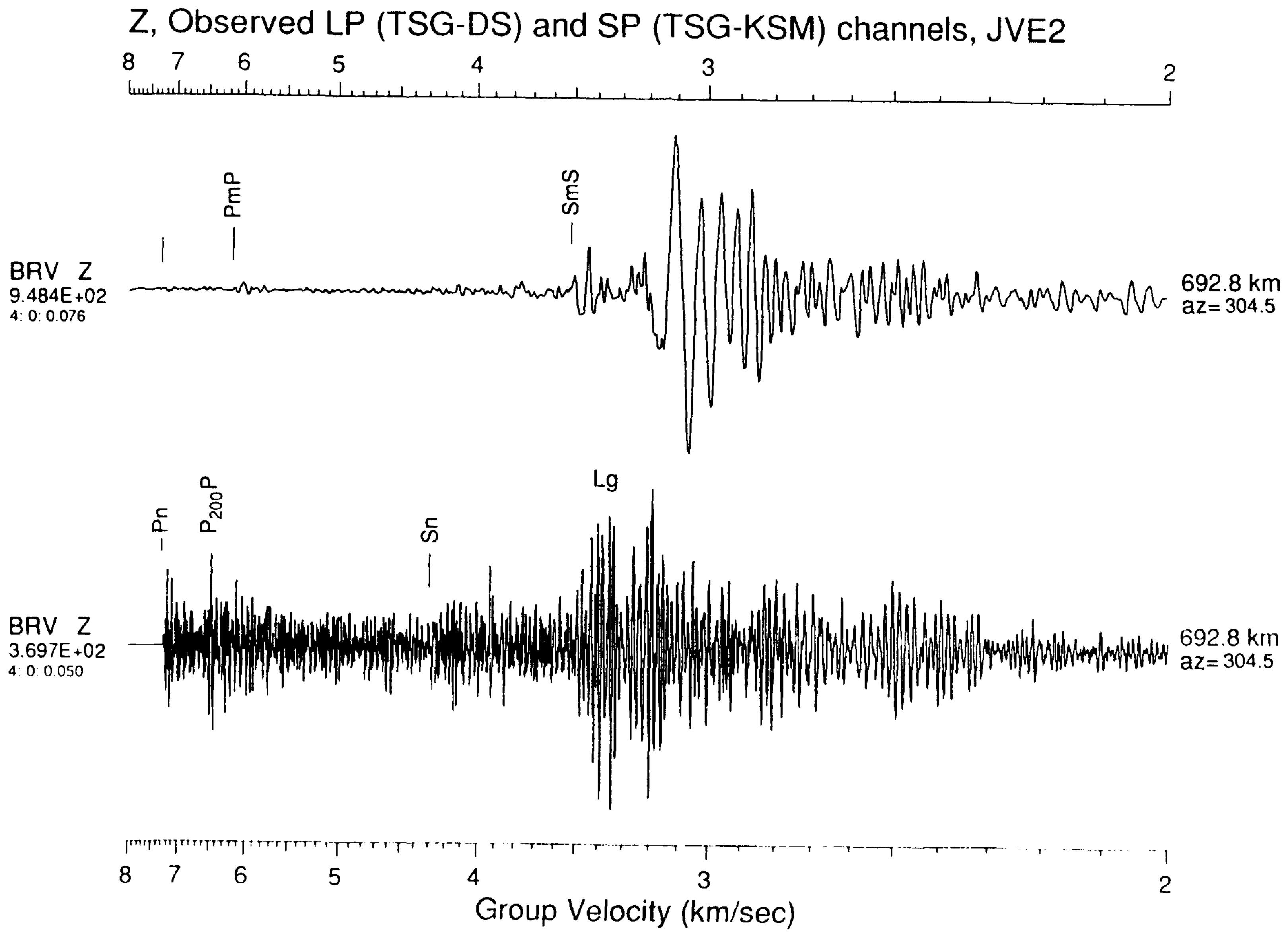


Figure 8: Long-period and short-period Borovoye records of the Joint Verification Experiment (explosion of 1988 September 14).

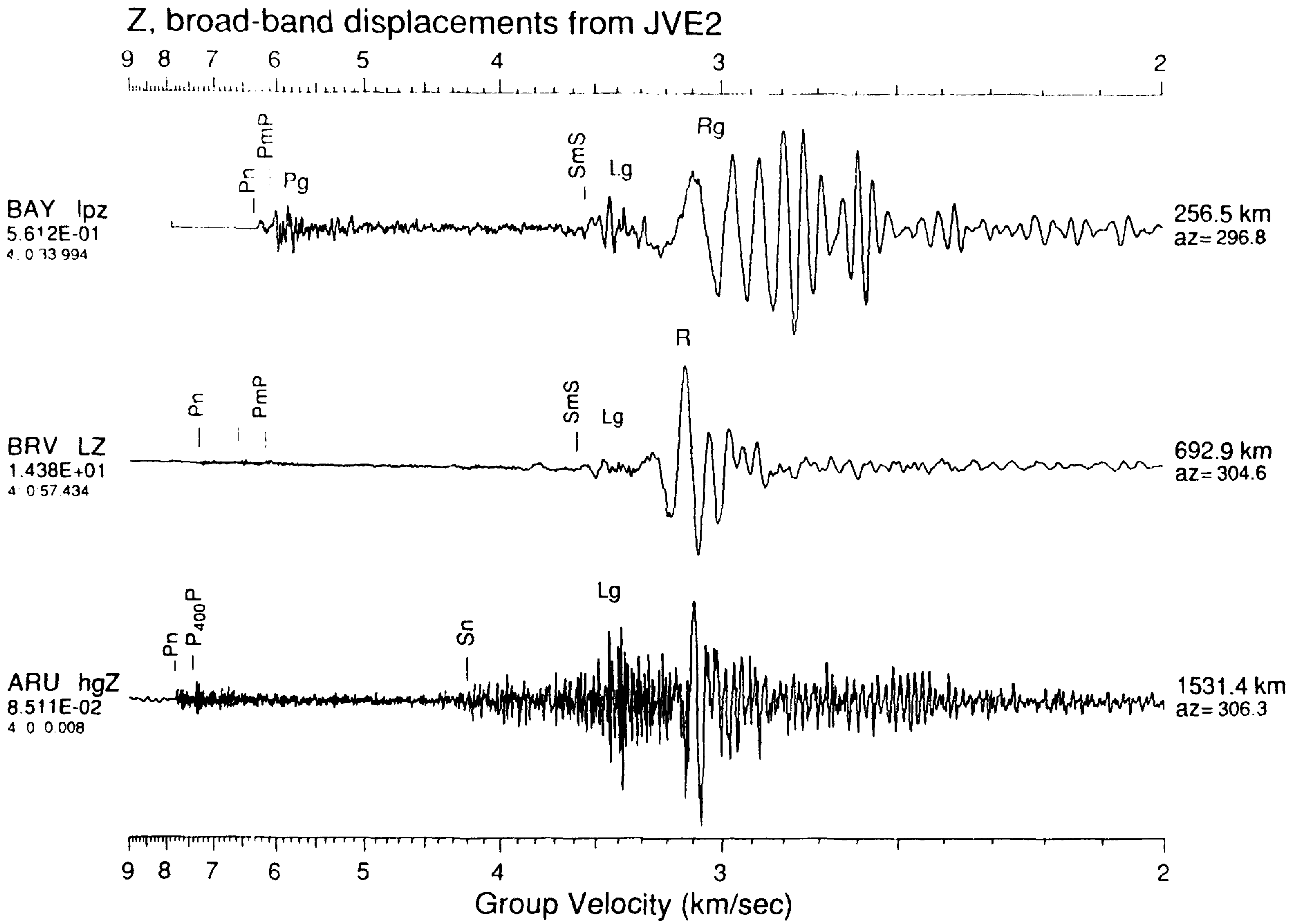


Figure 9: Broadband Borovoye records of the Joint Verification Experiment (explosion of 1988 September 14).

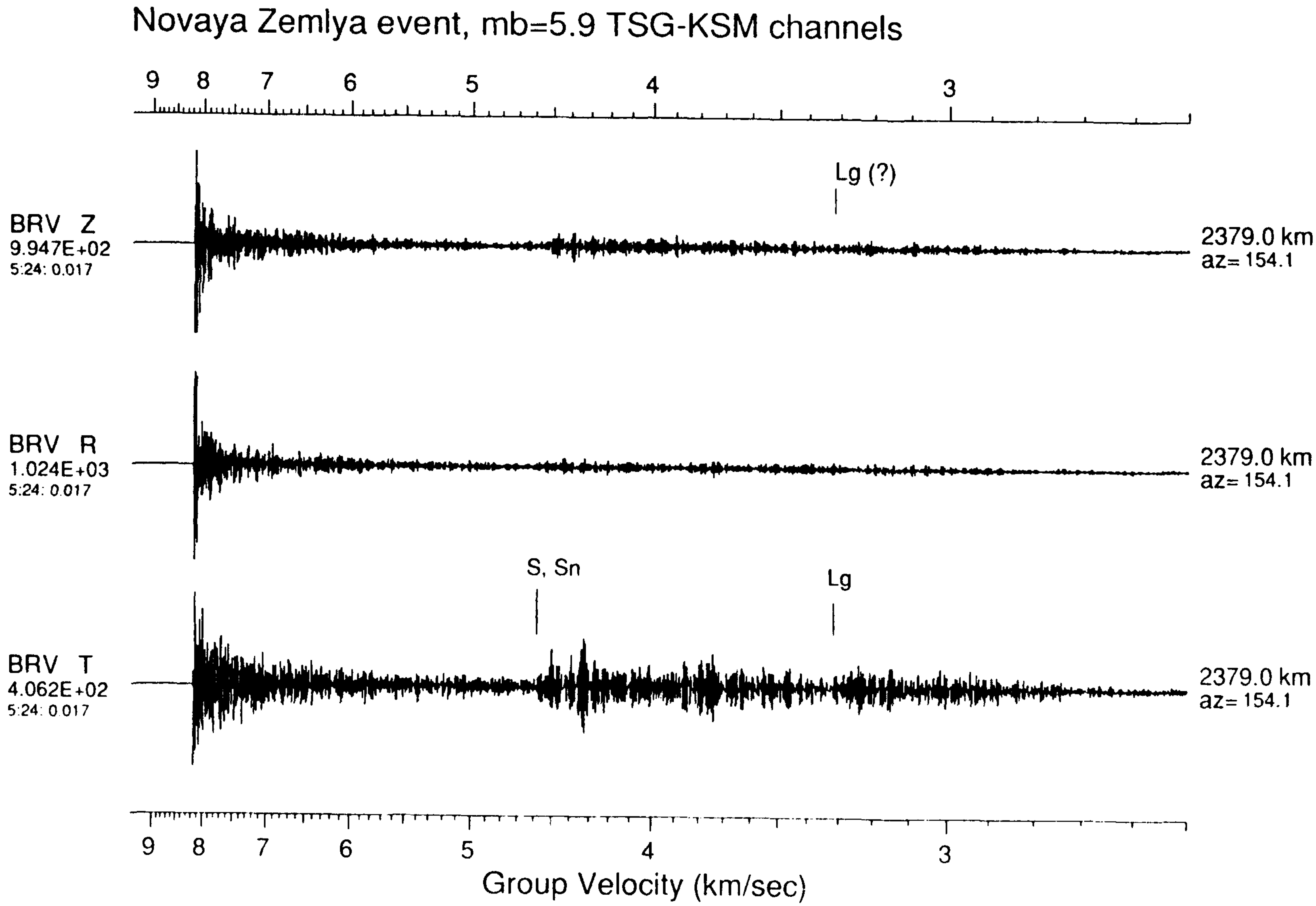


Figure 10: Short-period record at BRV of Novaya Zemlya explosion of 1988 December 4.

Event 1988/12/4

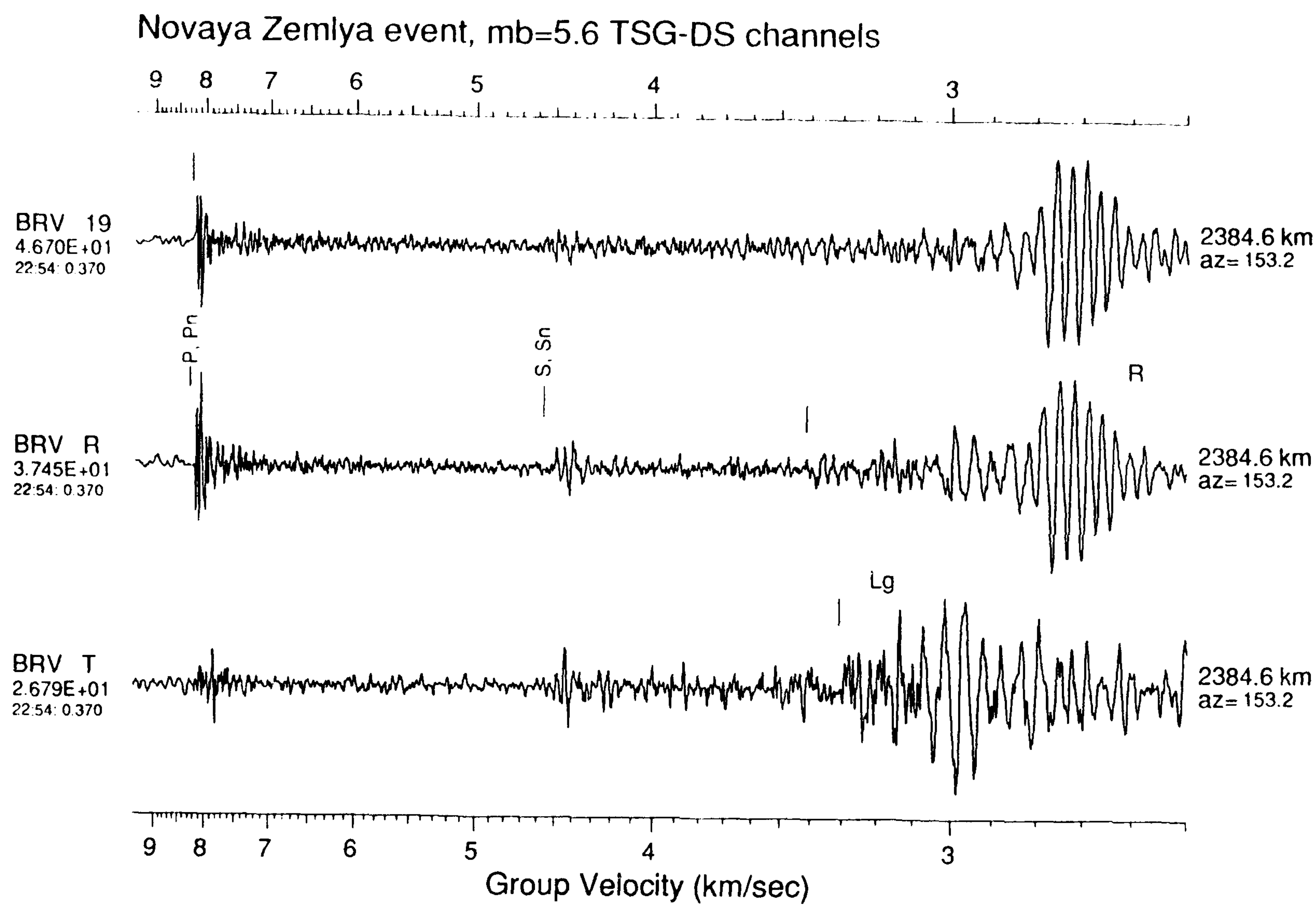


Figure 11: Long-period record at BRV of Novaya Zemlya explosion of 1988 May 7.

Event 1988/ 5/ 7

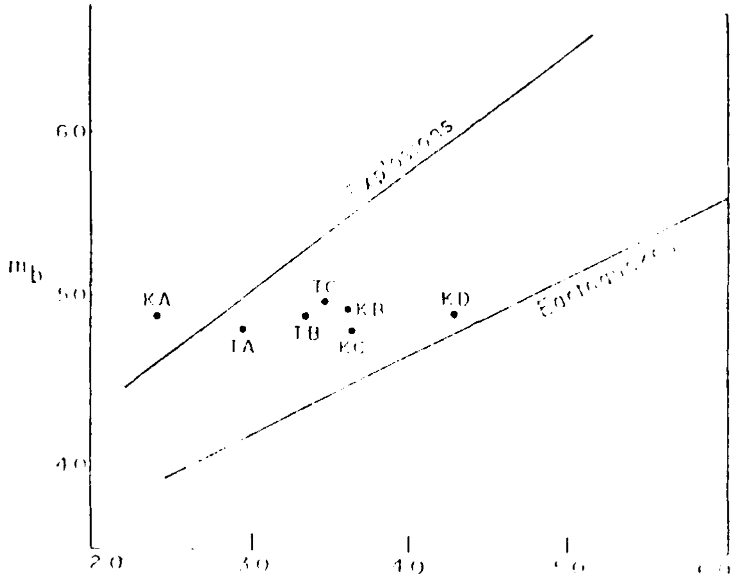
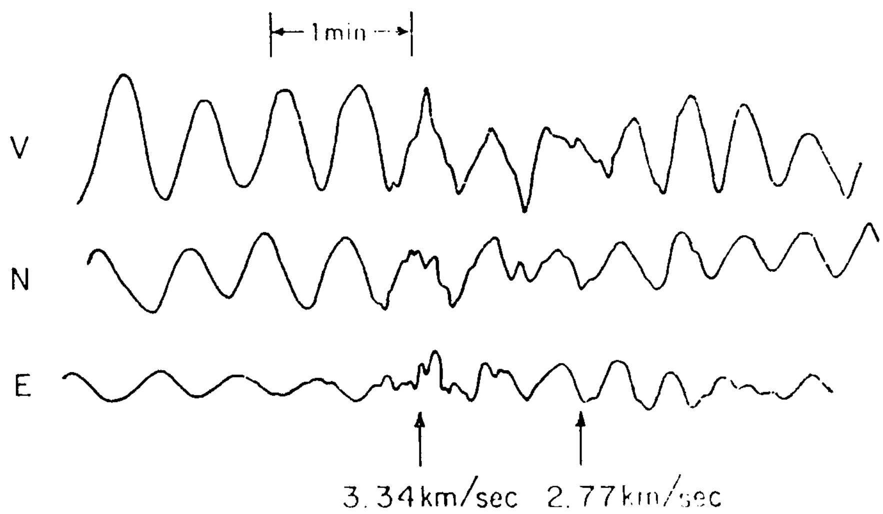


Figure 12: An m_b/M_s diagram from Landers (1972), based on M_s values computed by the method of Marshall and Basham (1972).



Event KA 5-1-69 at KBL 6k

The three components of the surface waves generated by the event KA as recorded at Kabul. The energy arriving with a group velocity of 3·34 km s^{-1} may be either Love or higher mode Rayleigh waves.

Figure 13: WWSSN data from the event of 1969 May 1.

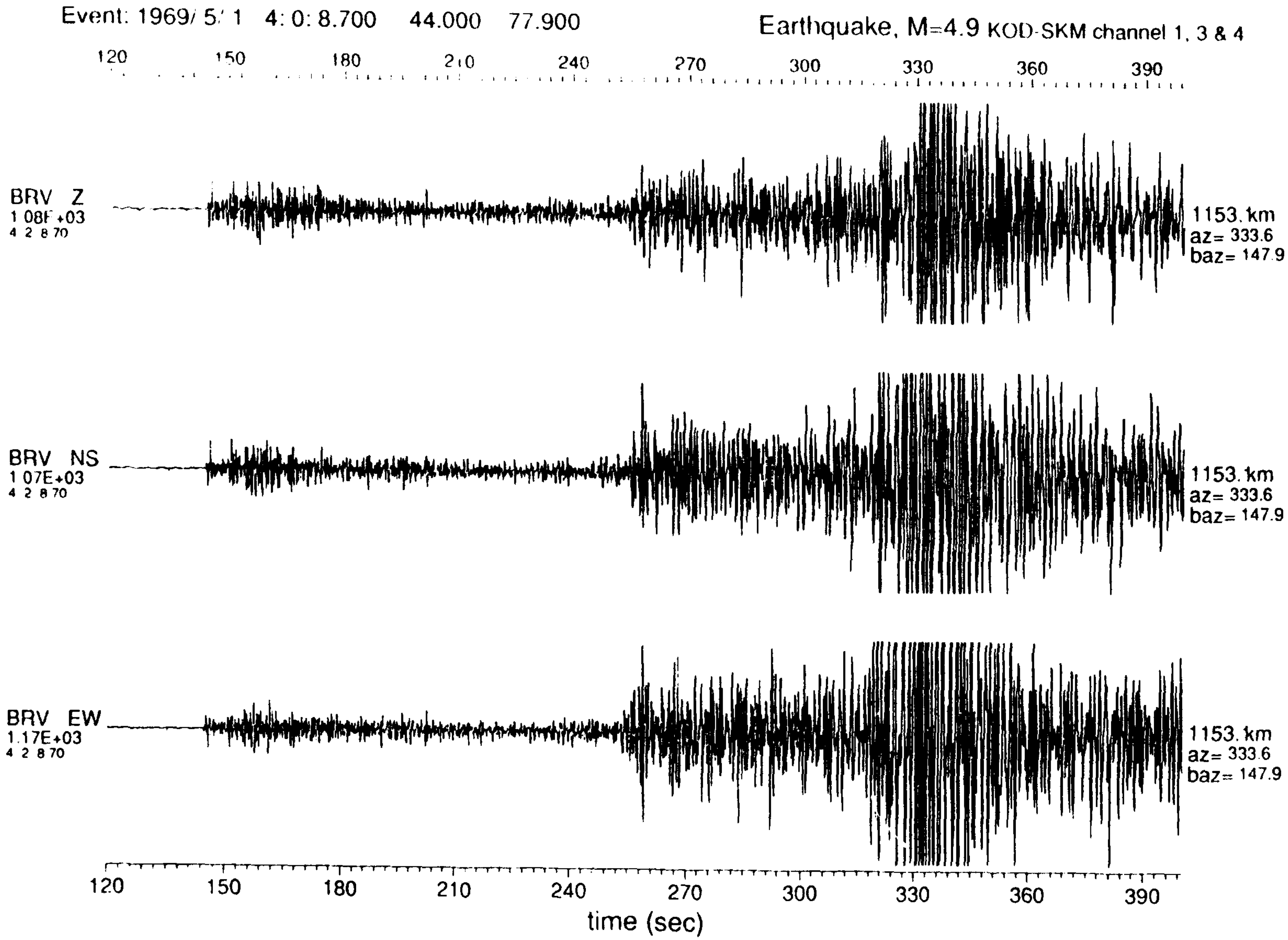


Figure 14: KOD digital data recorded at BRV for the event of 1969 May 1.

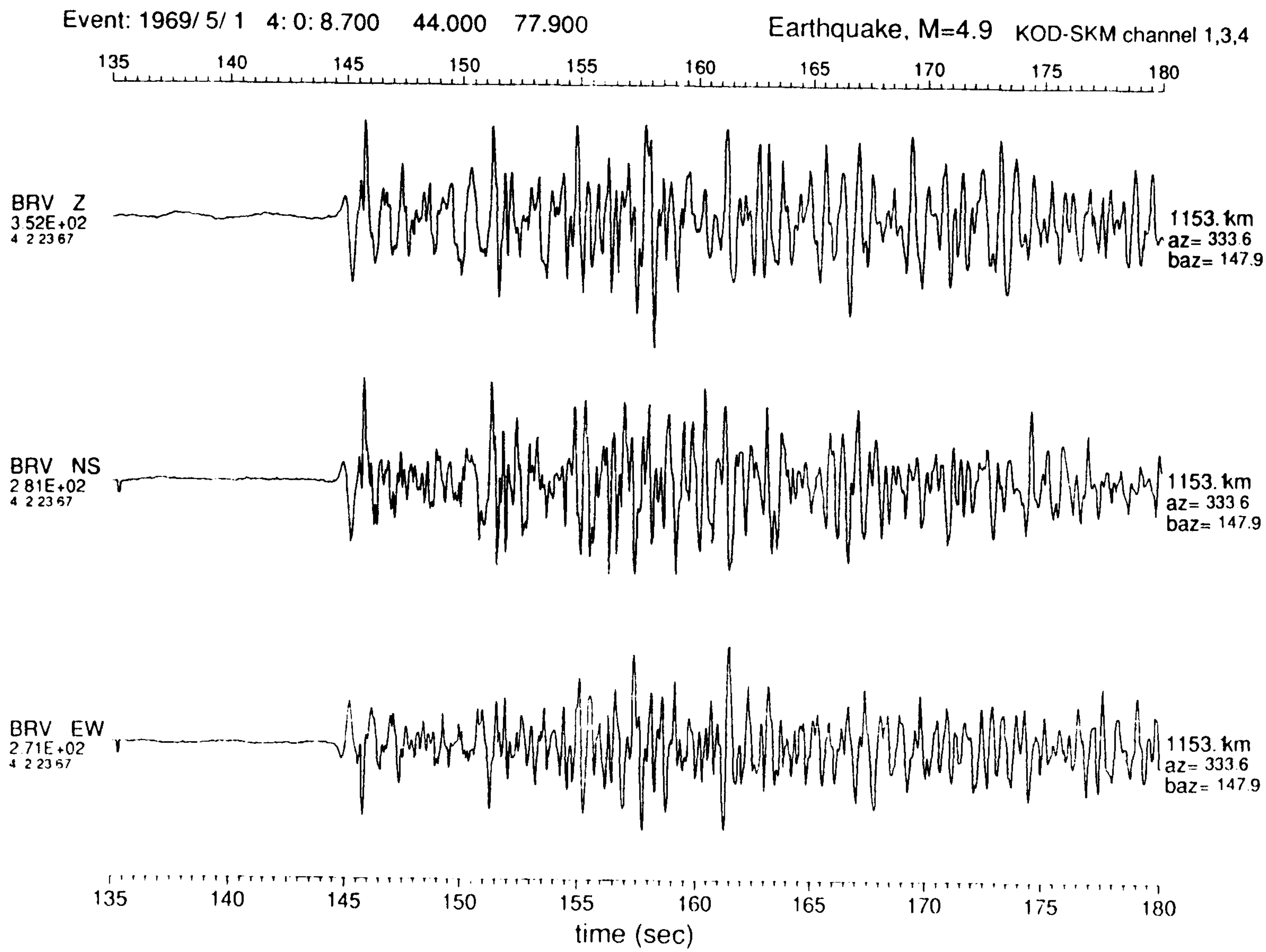


Figure 15: As Figure 14, but with expanded time scale.

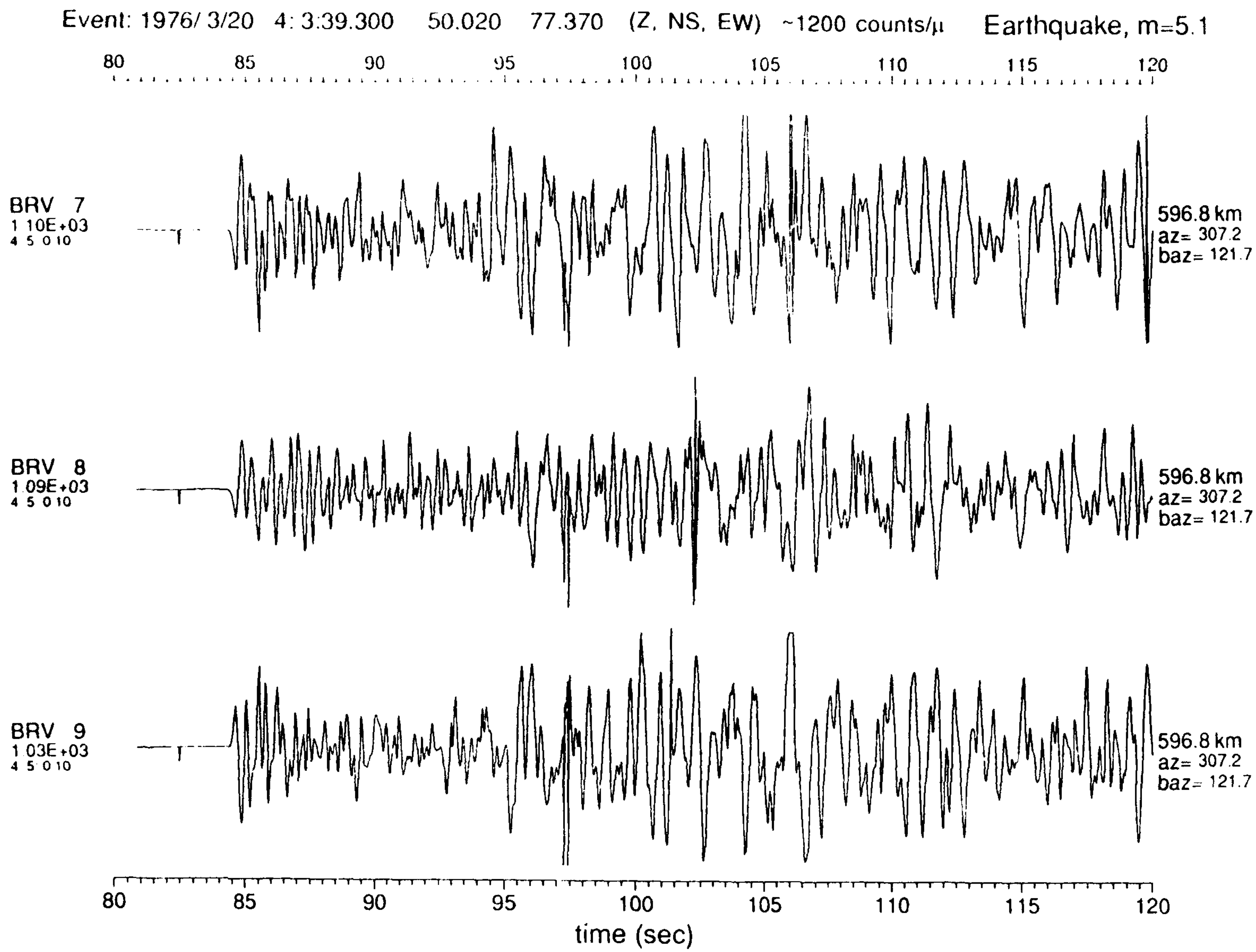


Figure 16: Short-period record at BRV of the Kazakhstan earthquake of 1976 March 20.

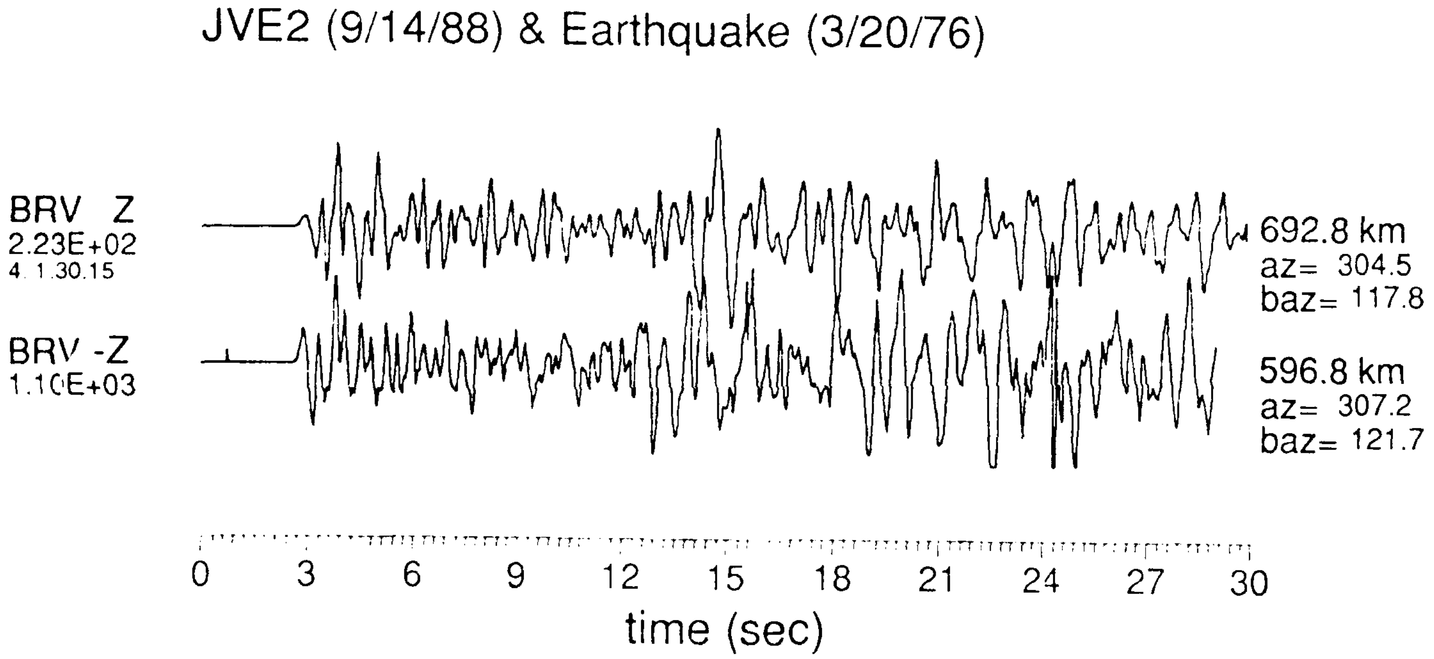


Figure 17: Comparison at BRV of an explosion signal, and the earthquake signal of 1970 March 20, both on short-period vertical instruments.

JVE2 (9/14/88) & Earthquake (3/20/76)

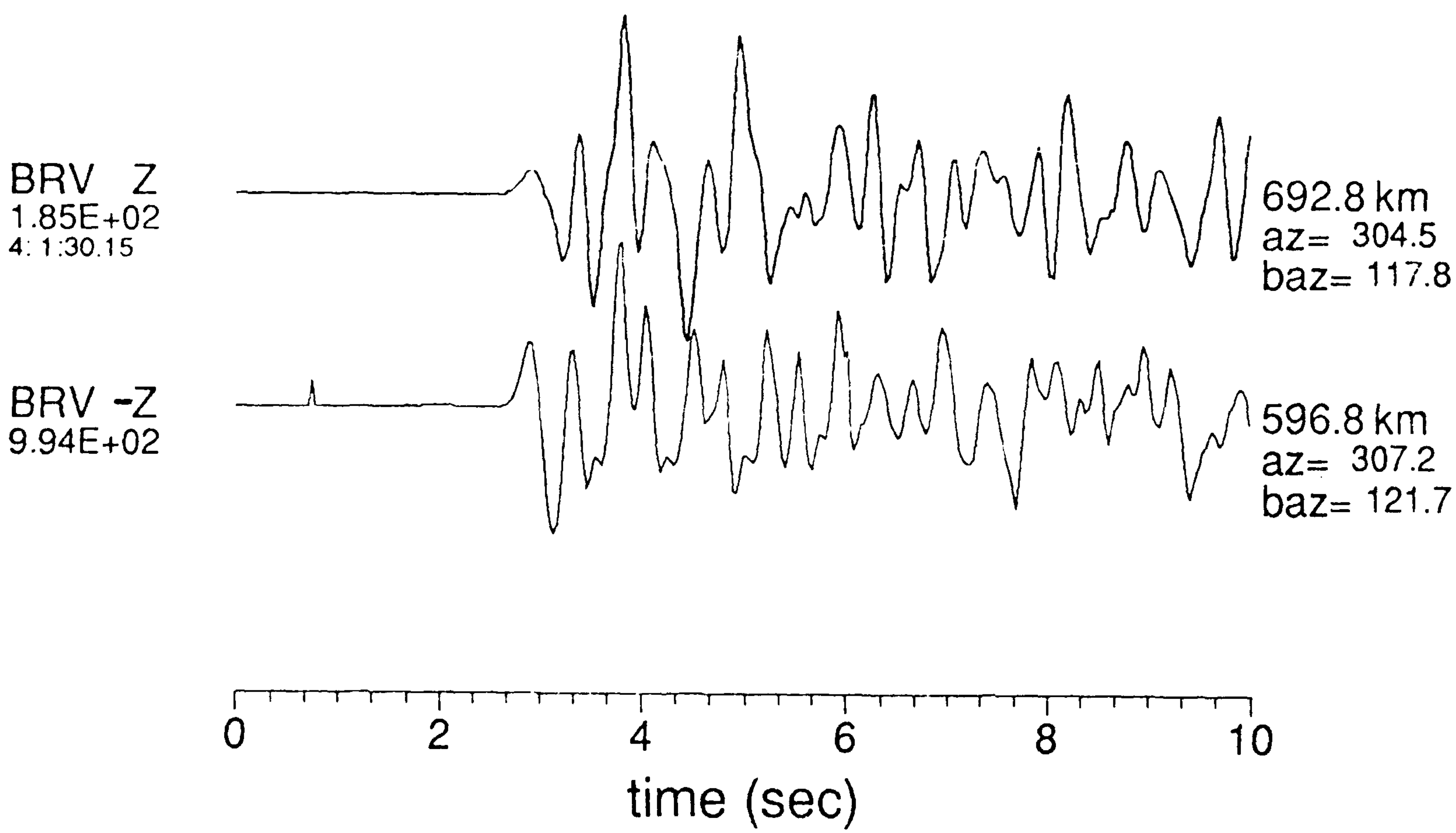


Figure 18: As Figure 17, but with expanded time scale.

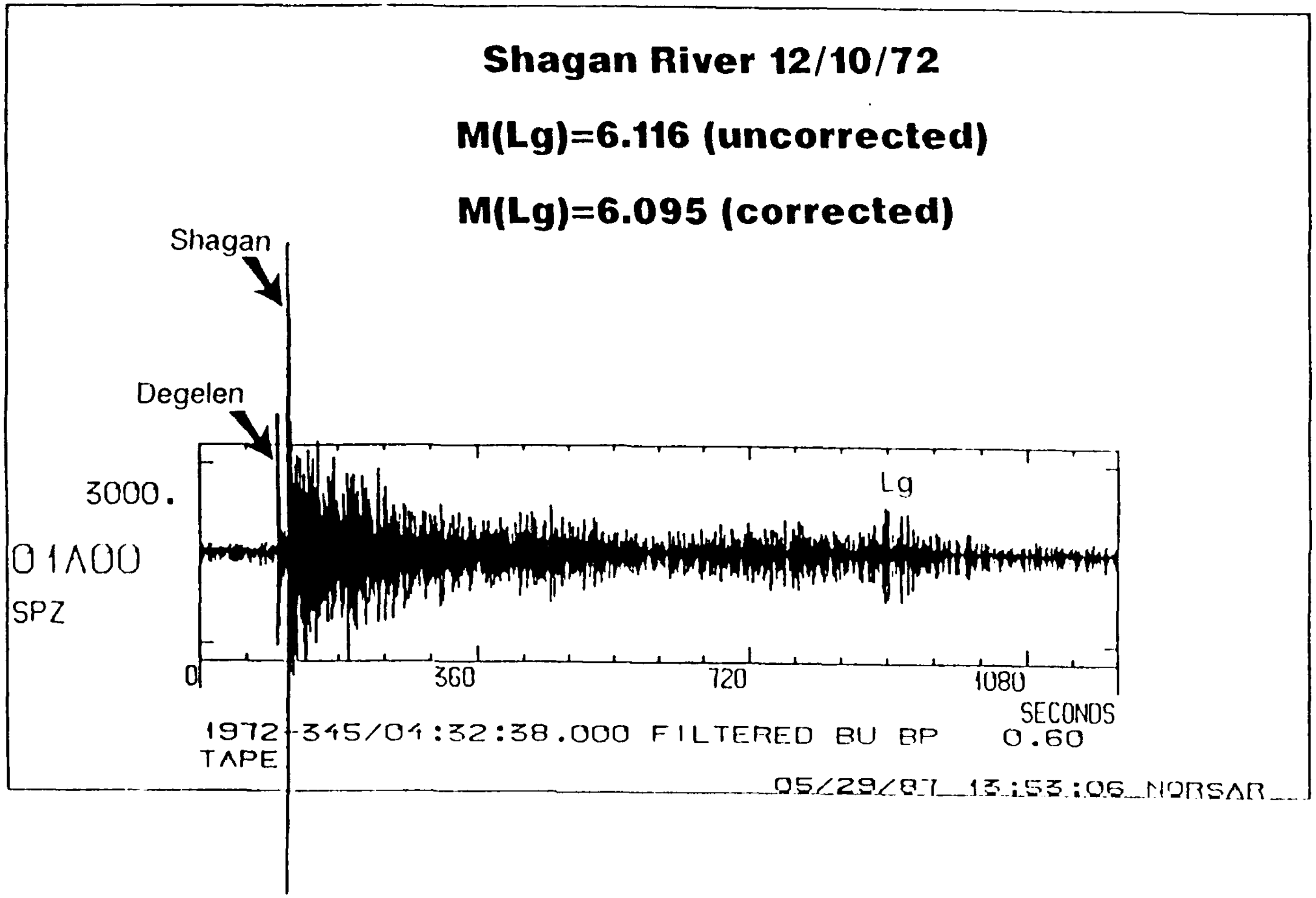


Figure 19: NORSAR signal from the double explosion of 1972 December 10 (from Ringdal, 1989).

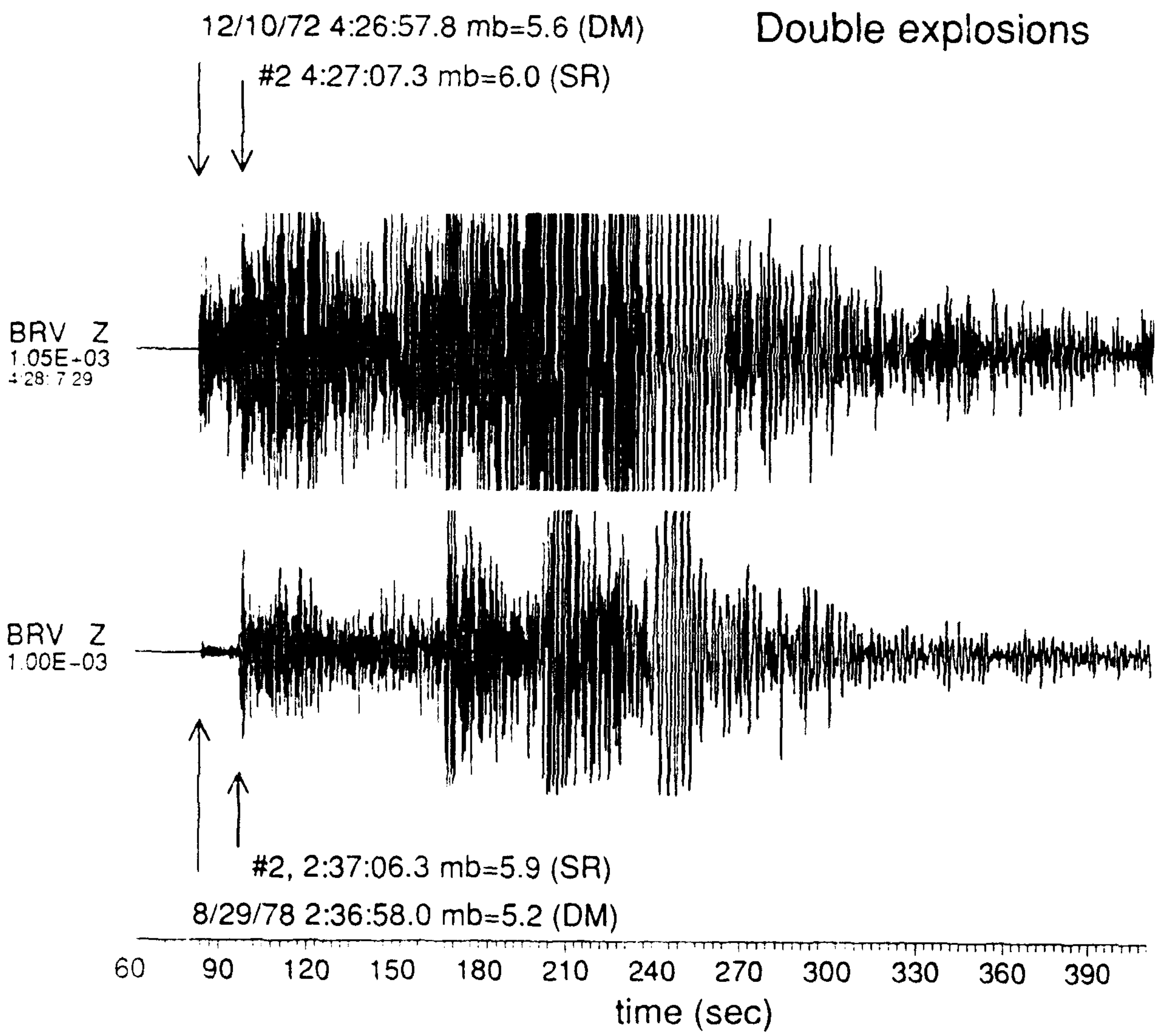


Figure 20: The short-period BRV records of two double explosions.

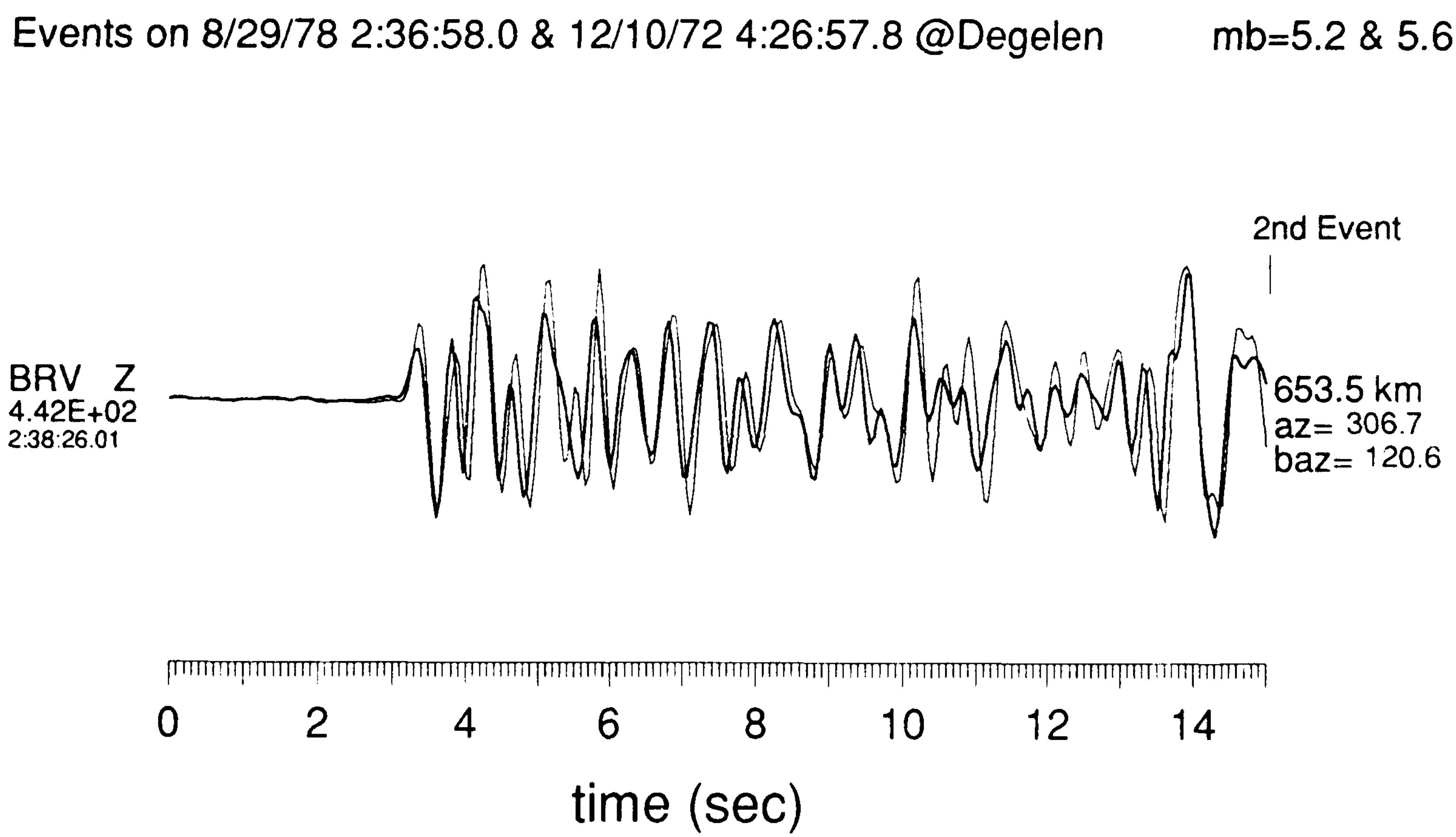


Figure 21: Comparison of two Degelen explosions, recorded at BRV. Compare this display with the beginning of the top traces of Figure 6 and 7, to appreciate the merits of digital recording.

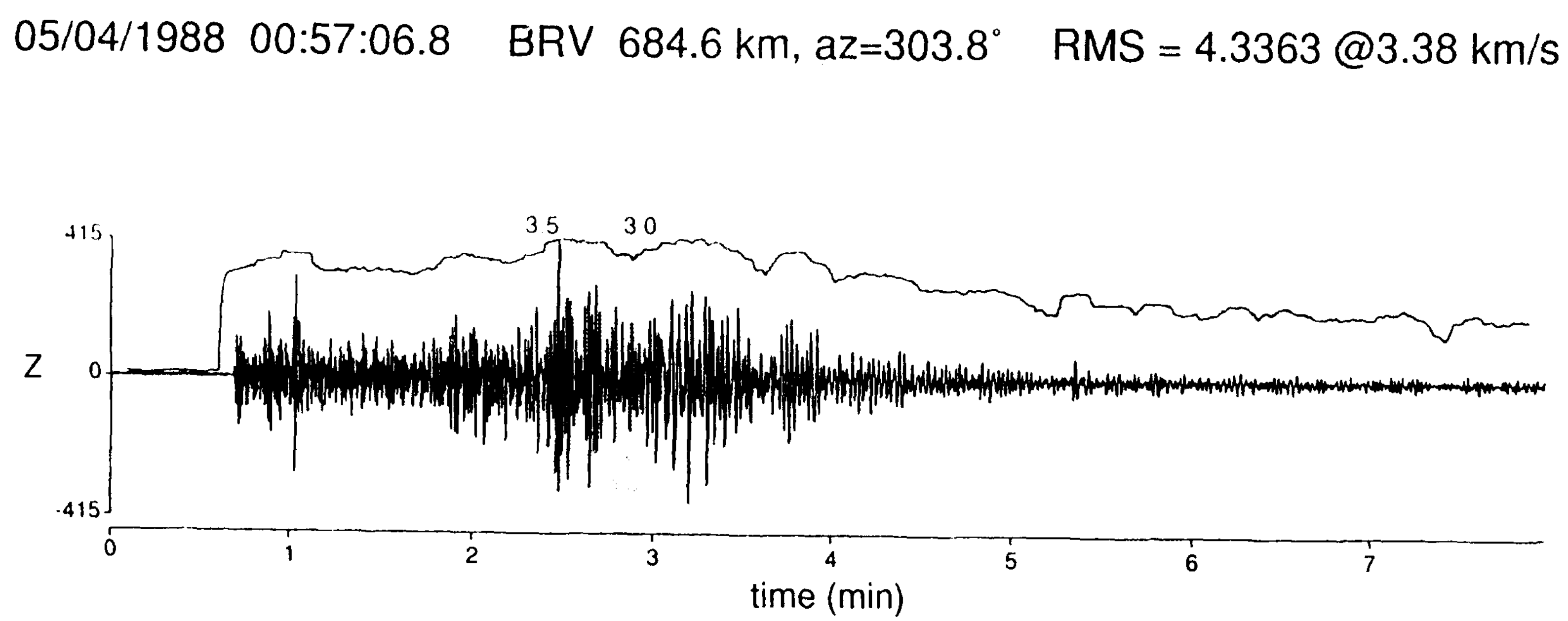


Figure 22: Analysis of RMS Lg, showing choice of window, and the values of the moving average (as a function of time).

5 Shagan Explosions, slope = 1.84 sigma = 0.05

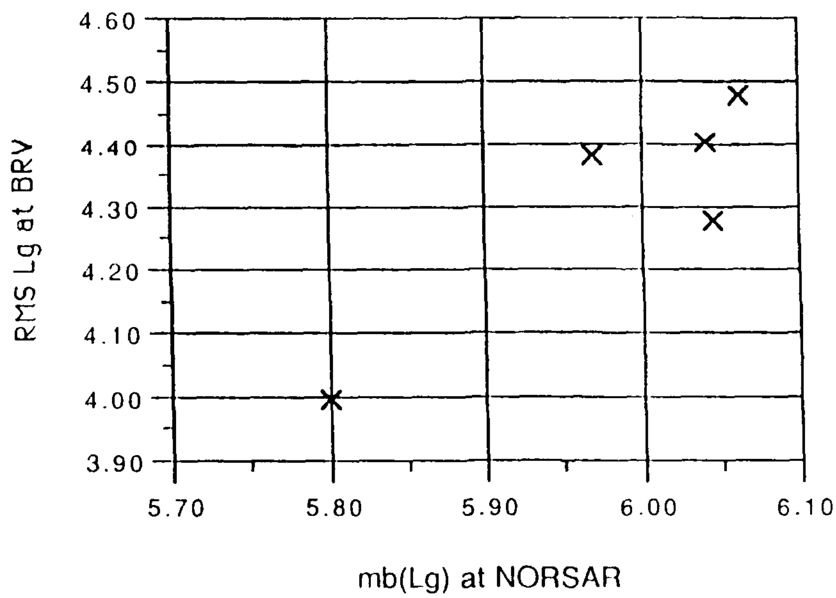


Figure 23: Comparison of RMS Lg measurements at BRV and NORSAR, for five Shagan River explosions.

6 Shagan Explosions, slope = 1.63 sigma = 0.06

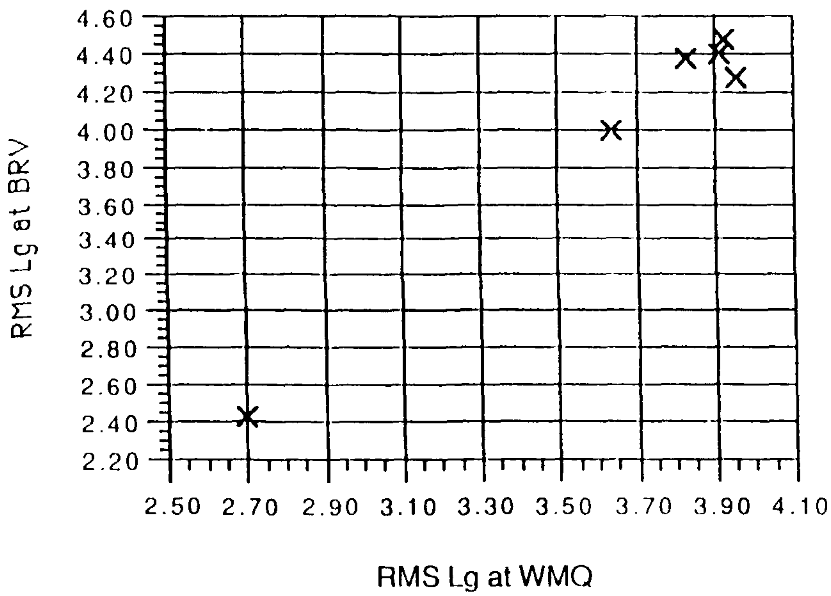


Figure 24: Comparison of RMS Lg measurements at BRV and WMQ (China), for six Shagan River explosions.

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